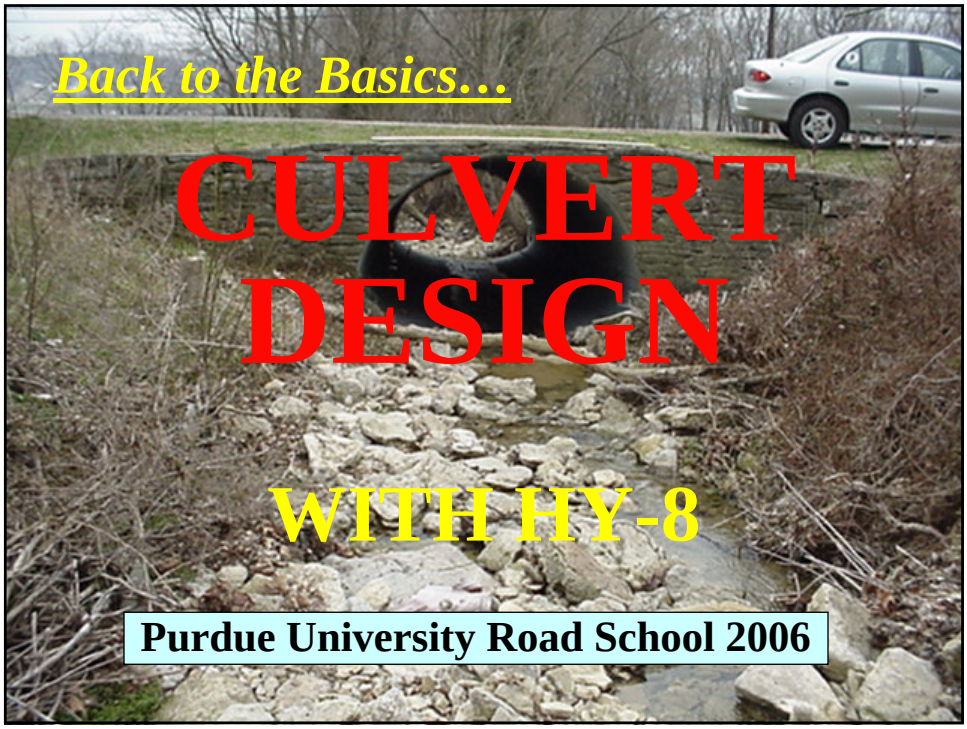


Your Presenters…

Merril Dougherty
INDOT, Hydraulics Unit Supervisor

David Finley
CTE Engineers, Inc.
CTE | AECOM

Part One:
Culvert Hydraulics…

We need to begin with Open Channel Hydraulics…

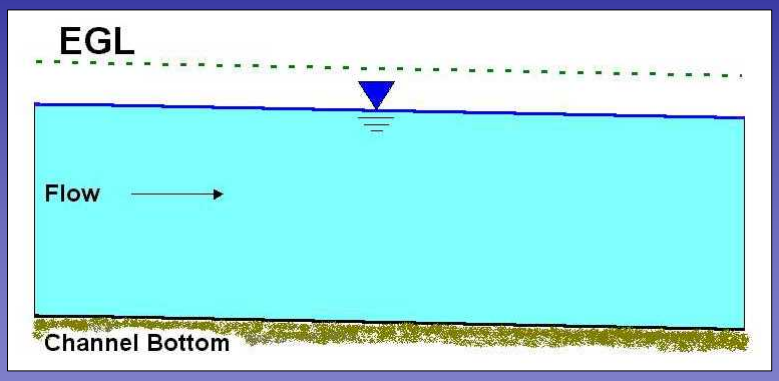
Why?

Well, how do you define Open Channel Flow?

Gravity

Hydraulics of Culverts:

NORMAL DEPTH

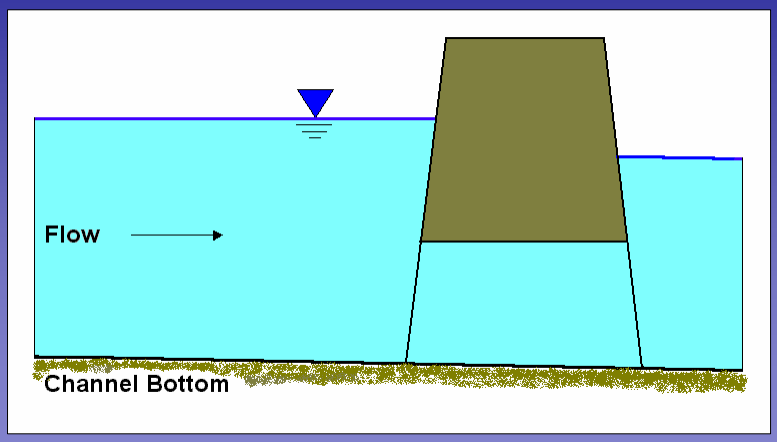


Everything is paralle1!

Depth = *f* (flow, slope, channel characteristics)

Hydraulics of Culverts:

BACKWATER



A constriction to flow will create BACKWATER...

Hydraulics of Culverts:

Subcritical Flow

vs.

Supercritical Flow

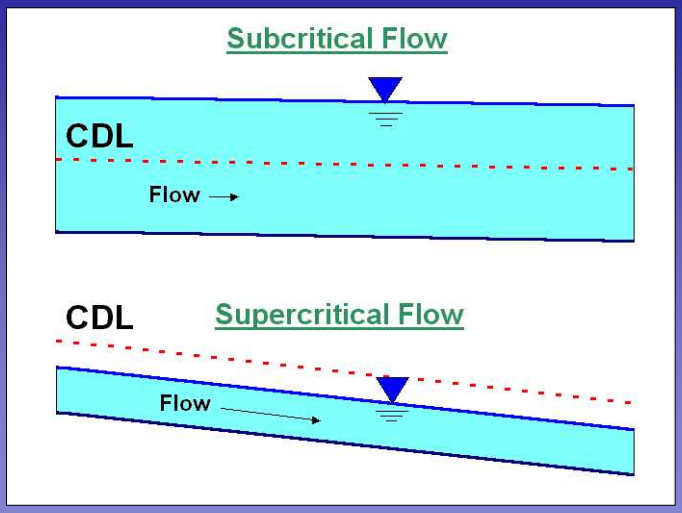
Drop a rock into the flow….

What happens?

Put and obstruction into the flow...

What happens?

Hydraulics of Culverts:
Subcritical Flow vs. Supercritical Flow



Hydraulics of Culverts:
Froude Number

$$Fr = \frac{V}{\sqrt{gy}}$$

Velocity is related to inertial forces…

Depth is related to energy forces…

If Fr < 1, Energy Forces dominate (subcritical)

If Ff > 1, Momentum dominates (supercritical)

Hydraulics of Culverts:
Supercritical Flow

Critical Depth =

***f* (flow, channel characteristics)**

ONLY!

ANY QUESTIONS?

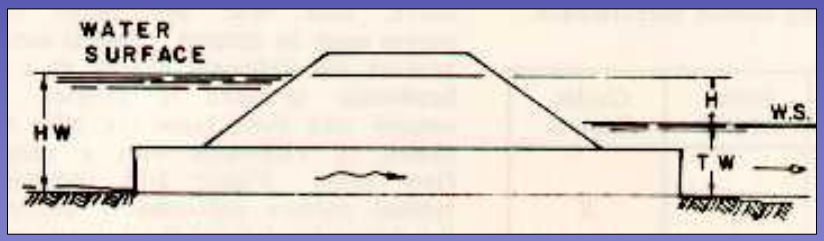
Hydraulics of Culverts:

Full Flow or Partly Full Flow?

Hydraulics of Culverts:

Full Flow:

High Tailwater



Hydraulics of Culverts:

Full Flow:

Low Tailwater

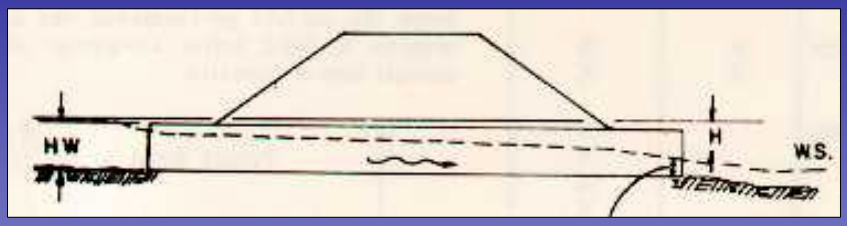
Now, here's another example...

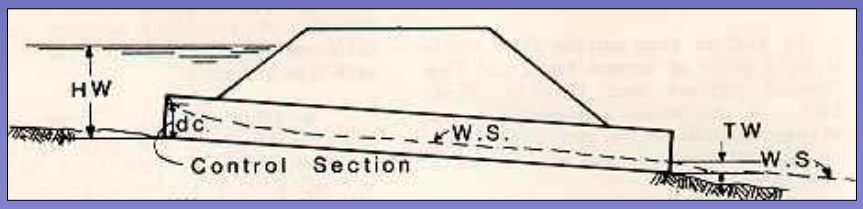
Hydraulics of Culverts:

Full Flow: Low Tailwater

Hydraulics of Culverts:

Partly Full Flow

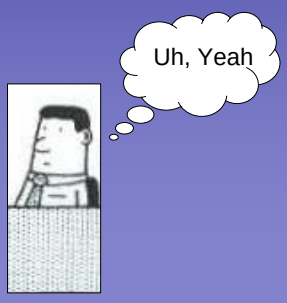




Hydraulics of Culverts:

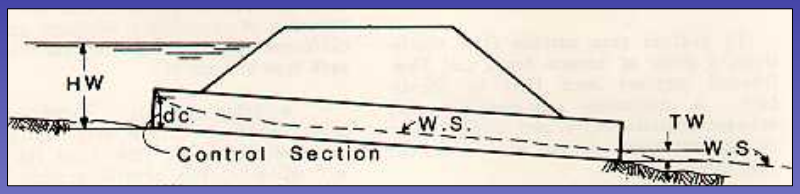
CONTROL POINT

"The point in the water surface profile through the culvert at which there is a unique relationship between the depth and the discharge…"



Hydraulics of Culverts:

CONTROL POINT

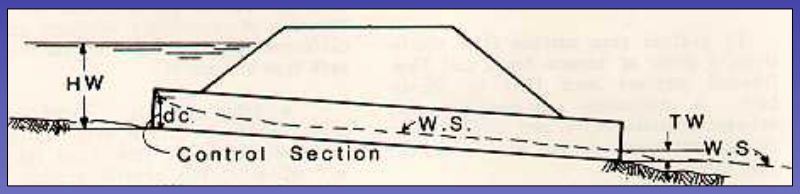


The control point determines what the rest of the water surface profile will look like…

…it's the point where you *know* how to compute the water surface elevation.

Hydraulics of Culverts:

INLET CONTROL

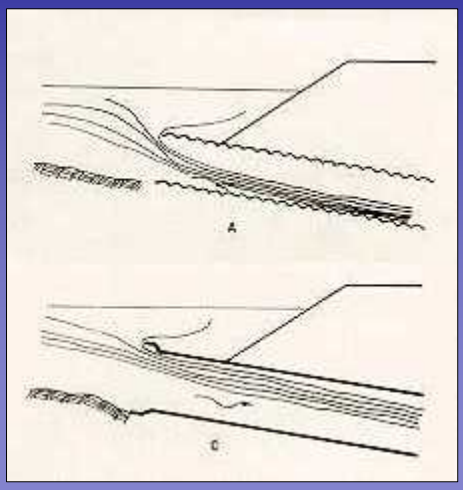


Steep slope -- Flow is Supercritical in the culvert!

Somewhere, an hydraulic jump will occur...

Hydraulics of Culverts:

INLET CONTROL

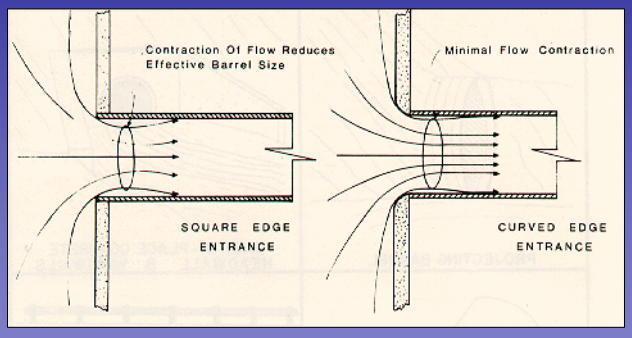


Headwater is controlled only by head loss at the inlet!

RCP "Bell" end vs. CMP thin edge...

Hydraulics of Culverts:

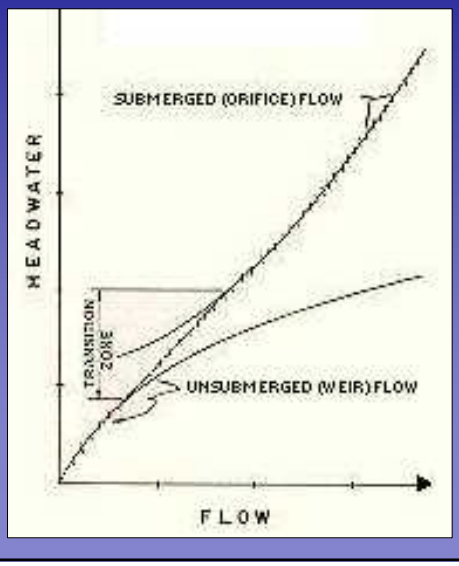
INLET CONTROL



A cambered entrance will (theoretically) reduce head loss at the inlet...

Hydraulics of Culverts:

INLET CONTROL



Flows at the Inlet:

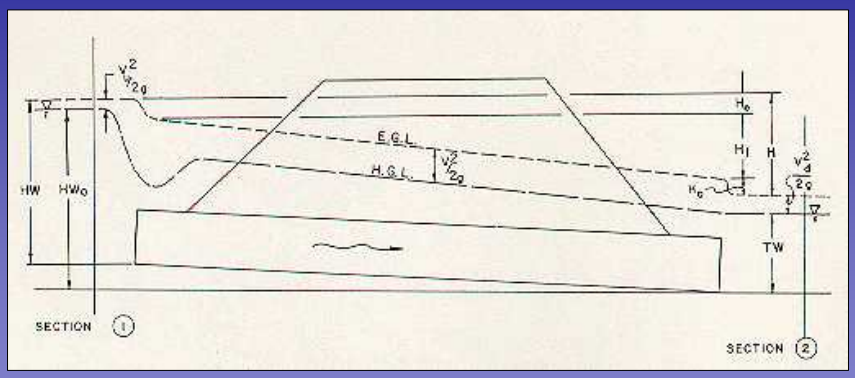
Weir Flow

or

Orifice Flow...

Hydraulics of Culverts:

OUTLET CONTROL

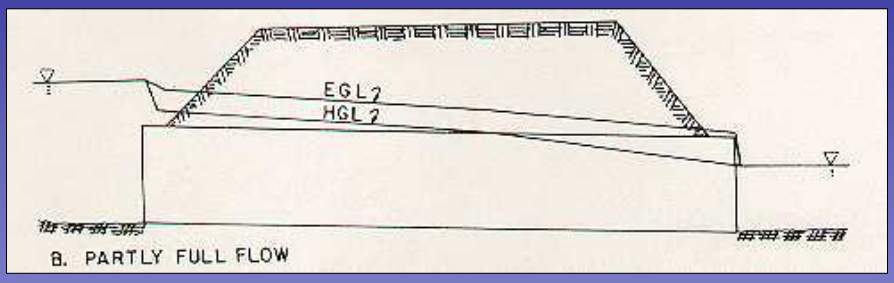


Subcritical flow…

HW = *f* (TW, outlet loss, barrel friction, inlet loss)

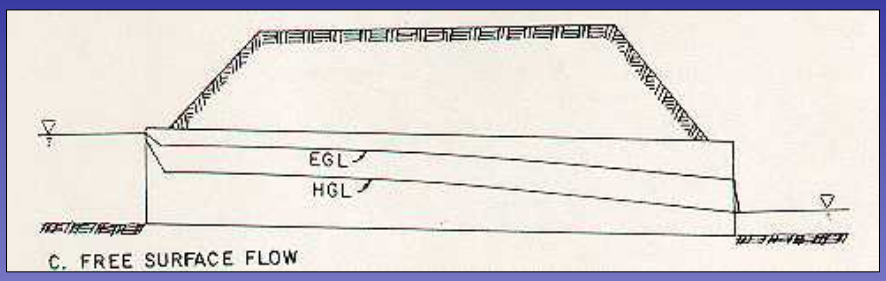
Hydraulics of Culverts:

OUTLET CONTROL



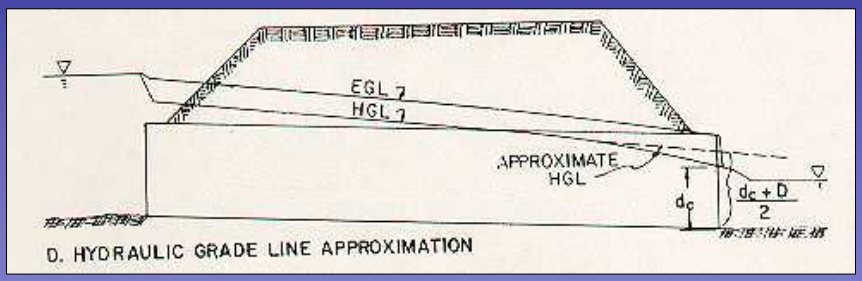
Hydraulics of Culverts:

OUTLET CONTROL



Hydraulics of Culverts:

OUTLET CONTROL



Hydraulic Grade Line Approximation!

$$h_o = (d_c + \text{Rise}) / 2$$

ANY QUESTIONS?

Part Two:
Using HY-8 to Design Culverts…

Start by collecting the information you will need…

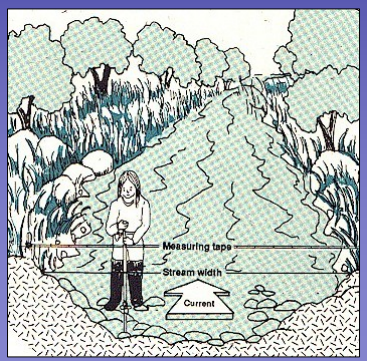
Using HY-8 to Design Culverts

Information you will need

First, determine the flow rate based upon the storm frequency…

For IDNR, use the 100-year discharge,

For INDOT…



Using HY-8 to Design Culverts

For INDOT…

there are three criteria to consider:

Functional Classification	Allowable Backwater	Roadway Serviceability	Allowable Velocity
Freeway	Q_{100}	Q_{100}	Q_{50}
Multilane Non-Freeways	Q_{100}	Q_{100}	Q_{50}
Two-Lane Facilities			
AADT ≥3000	Q_{100}	Q_{100}	Q_{50}
3000 > AADT ≥1000	Q_{100}	Q_{25}	Q_{25}
AADT < 1000	Q_{100}	Q_{10}	Q_{10}
Driveways	Q_{100}	Q_{10}	Q_{10}

Note: The design storm frequency for culvert extension structures is identical to those for new culvert structures. Traffic volumes are for a 20-year projection.

Using HY-8 to Design Culverts

Information you will need

CULVERT DATA :

- **Size, Length, Invert Elevations…**
- **The inlet MUST be above the outlet!**

Using HY-8 to Design Culverts

Available Shapes in HY-8

HY-8 will analyze…

Round…

Deformed…

Elliptical…

…and pipe arches – But also…

Using HY-8 to Design Culverts

Available Shapes in HY-8

3 and 4-sided boxes…

3-sided arch-boxes…

Super-Span arches and…

Irregular Shapes!

(X, Y-bottom, Y-top)

Using HY-8 to Design Culverts

Available Shapes in HY-8

What would you use for this????

Using HY-8 to Design Culverts

Available Shapes in HY-8

Would you use a Box Shape here?

Using HY-8 to Design Culverts

Available Shapes in HY-8

How about this one????

Using HY-8 to Design Culverts

Analyzing an existing culvert is one thing…

…but how do you select a culvert type for a new design?

Using HY-8 to Design Culverts

Selecting a Proposed Shape

Priority System

Trial 1 - Single Circular Pipe
Trial 2 - Single Deformed Pipe
Trial 3 - Single Specialty Structure
Trial 4 - Multiple Circular Pipes
Trial 5 - Multiple Deformed Pipes
Trial 6 - Multiple Specialty Structures

Using HY-8 to Design Culverts

Selecting a Proposed Shape

Pipe Culvert Interior Designation

Smooth Interior:
Manning's n = 0.012

Corrugated Interior:
Manning's n = 0.024

Using HY-8 to Design Culverts

Selecting a Proposed Shape

Minimum Culvert Size

Structure Application	Minimum Circular Pipe Size	Minimum Deformed Pipe Size
Driveway Culvert	**15 inches**	**1.1 sf (17" x 13")**
Mainline/Public Road Approach Culvert (2 lanes)	**15 inches**	**1.1 sf (17" x 13")**
Mainline/Public Road Approach Culvert (3 + Lanes)	**36 inches**	**6.5 sf (42" x 29")**

Using HY-8 to Design Culverts

Information you will need

ROAD PROFILE DATA :

Either matters a lot, or not at all…

Enter…

- **Station and elevation data or**
- **A constant elevation!**

Using HY-8 to Design Culverts

Road Profile Data…

Enter station/ elevation data…

Using HY-8 to Design Culverts

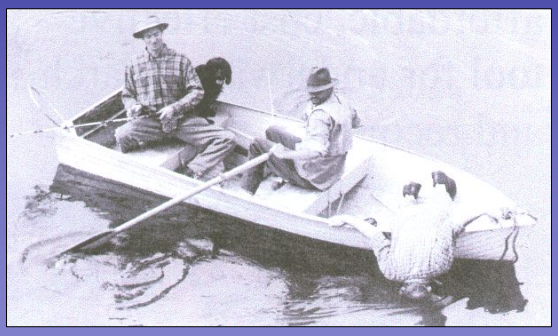
Road Profile Data…

Enter a constant elevation…

Using HY-8 to Design Culverts

Information you will need…

TAILWATER CROSS SECTION :



HY-8 uses a single stream cross section at the downstream end of the culvert

So, what options do you have to define this cross section?

Using HY-8 to Design Culverts

Determining a Tailwater Cross Section…

Options…

1. **"Regular" cross sections: Rectangular, Trapezoidal, Triangular…**
2. **"Irregular"** ***(Station – Elevation Data)***
3. **"Known" rating curve…**
4. **Constant elevation**

Using HY-8 to Design Culverts

Determining a Tailwater Cross Section…

What would you use for this?

Using HY-8 to Design Culverts

Determining a Tailwater Cross Section…

What would you use for this?

Using HY-8 to Design Culverts

Determining a Tailwater Cross Section…

What would you use for this?

Using HY-8 to Design Culverts

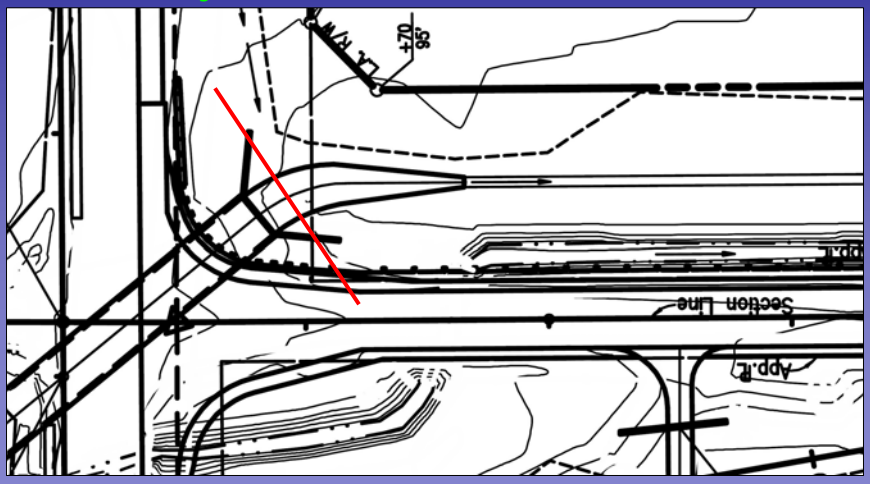
Determining a Tailwater Cross Section…

What would you use for this?

Using HY-8 to Design Culverts

Determining a Tailwater Cross Section…

Would you take the cross section here?



ANY QUESTIONS?

Using HY-8 to Design Culverts

LET'S TRY A DESIGN EXAMPLE!

But remember to always check your results!